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# Experimental investigation on liquid permeability of tight rocks under back pressure conditions

Jian Tian, Lijun You*, Pingya Luo**, Yili Kang, Dujie Zhang

State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, 610500, PR China

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ABSTRACT

With the popularity of unconventional reservoirs having the remarkable features of extremely low permeability and low porosity, liquid permeability measurement of tight rocks from the unconventional reservoirs is facing severe challenges. At laboratory, it will require a high displacement pressure (which is the differential pressure between two pressure sensors during the measurement) gradient and a long testing time to measure liquid flow rate of tight rocks without a back pressure normally. In fact, reservoir fluid flow exists a back pressure and the production pressure gradient (simulated by displacement pressure gradient at laboratory) cannot be as high as it exerted in laboratory. To better simulate the reservoir liquid flow behavior and to investigate the effect of back pressure on liquid flow in tight rocks, we measured the liquid flow rate and studied the pressure transmission by exerting back pressure at the outlet of core samples during the experiment. The results showed that the liquid flow rate of tight rocks improved as a function of increasement in back pressure, and that it will shorten the testing time and reduce the desired displacement pressure to measure liquid permeability in tight rocks by exerting a back pressure. Based on our work, this paper aims to offer an effective method in liquid permeability measurement of tight rocks, and expect to provide an inslight into liquid flow behavior in tight rocks.

## 1. Introduction

As an basic physical property of porous media, permeability attracts great attention in many scientific and engineering fields (Zhou et al., 2017; Yang et al., 2017; Tan et al., 2017; Zhang, 2017; Eshghinejadfard et al., 2016; Sebben and Werner, 2016; Lai et al., 2016). The permeability of rocks can be described as gas permeability and liquid permeability according to the testing media. In oil and gas industry, liquid permeability measurement is hot issue. It refers to many links in core analysis such as relative permeability test (Kianinejad et al., 2016; Zeinijahromi et al., 2016; Zhang et al., 2016a; Jianlong et al., 2015; Alizadeh and Piri, 2014), oil recovery calculation (Ma et al., 2016a; Wang et al., 2017), reservoir fluid sensitivity evaluation (Zuloaga et al., 2017; Khan et al., 2017; Ma et al., 2016b; GuYuetianLiuZhangxinChen, 2014), and reservoir working fluid damage test (Xu et al., 2017; Lei et al., 2017; FarahDidier-Yu and Yu-Shu, 2014; Gentzis et al., 2009). Liquid permeability of tight rocks can be calculated via some flow mathematical models in porous media (Cui et al., 2017). Compared with model calculation, the results obtained from experimental measurement are more authentic because the models have ideal assumptions that are hard to satisfy the practical situation. The liquid flow rate of tight rocks is extremely low during the measurement process. As a result, it might cause the error in the permeability calculation when the measured liquid flow rate is not accurate (Zhang et al., 2016b). Sometimes, the liquid flow rate cannot be measured successfully (Wei et al., 2011). Therefore, how to measure liquid permeability of tight rocks effectively is in urgent need of solution.

Low efficiency of pressure transmission is a key factor that makes liquid permeability measurement of tight rocks very difficult. For a rock of permeability less than 1mD, pressure transfers from the inlet to the outlet will take a long period of time (days or weeks), and the flow rate is too small to be measured very successfully. In order to enhance the efficiency of measurement, high displacement pressure is exerted usually. For example, it will exert a displacement pressure over 10MPa to displace liquid through a tight core with the length of 5cm, and the confining pressure (simulate the overburden pressure at laboratory) is just slightly higher than the inlet pressure (over 2MPa). However, such a high displacement pressure gradient cannot occur during the formation production process due to the fact that drawdown pressure is mainly consumed nearby the downhole, and the pressure gradient cannot be as high as it exerted in laboratory. Drawdown pressure (described as formation pore pressure minus well bottom hole pressure)

* Corresponding author.
** Corresponding author.
*E-mail addresses:* youlj0379@126.com (L. You), luopy@swpu.edu.cn (P. Luo).

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and confining pressure are the two types of key pressures that shoud be simulated during core flow experiments. Unlikely, the outlet of the core samples is just exposed to the atmosphere when liquid permeability is measured in traditional method. Correspondently, the measurement of liquid permeability of tight rocks under the atmospheric condition differs markedly from the downhole condition.

Many researchers began to study the influence of testing method on permeability measurement of tight rocks. They explored the effect of pore pressure on gas permeability, and focused on how the pore pressure influenced the gas slippage effect (Tanikawa and Shimamoto, 2006; Tadayoni and Valadkhani, 2012; Zeinijahromi et al., 2012; Brace et al., 1968a; Wu et al., 1998). They discovered that the gas slippage effect can be eliminated by applying a back pressure at the outlet of tight core samples during the measurement (You et al., 2013). Some liquid permeability measurement methods of tight rocks have already been explored, such as the transient-pulse method (Brace et al., 1968b; Walder and Nur, 1986; Jones, 1997), pressure oscillation method (Kranz et al., 1990; Fisher, 1992). These methods are essentially to establish core pore pressure by exerting a back pressure at the downstream end of core. Unfortunately, the application of these methods are limited due to their high performance requirement on instrument and equipment. No matter how it is, one point should be affirmed that it could improve the efficiency of liquid permeability measurement of tight rocks by these methods. People may question wether it would be work to measure liquid permeability of tight rocks by exerting a back pressure. They may hold an opinion that tight rocks have fine pore throats, low permeability, and it would be harder for the pressure transmission because there is some back pressure which seems to be a resistance at the outlet. To answer that question and to offer an effective method in liquid permeability measurement of tight rocks, in this study, we carried out the liquid flow rate measurement and pressure transmission experiment under back pressure conditions to study the effects of back pressure on liquid flow behaviors in tight rocks.

## 2. Materials and methods

### 2.1. Core samples and fluids

The core samples used in this study were taken from the He 8 member in Ordos basin, which has a massive tight oil potential in China (Han et al., 2014; Jia et al., 2012). The basic parameters of the core samples were measured under the confining pressure of 3MPa, as listed in Table 1. The reservoir lithology of the core samples is mainly quartz sandstone and the cardinal type of clay minerals is kaolinite. Simulated formation water was used to measure the flow rate in this study. Based on the formation water data, the salinity of the simulated formation water was established to be 66, 666 mg/L, the composition of the simulated formation is presented in Table 2. The simulated formation water was filtrated before the measurement process to prevent core permeability damage caused by the movement of solid particles in the simulated water (Sarkar and Sharma, 1990; Kalantari Dahaghi et al., 2011; Abbasi et al., 2012; Zeinijahromi, 2013).

### 2.2. Apparatus

The apparatus used to measure liquid flow rate were designed and assembled. The schematic of the apparatus was showed in Fig. 1. The main components of the apparatus were displacement pump, core holder, gas cylinder and back pressure valve. The work precision of the displacement pump was 0.001 mL/min, which guaranteed the reliability of the measured results. In order to regulate the core pore pressure, we controlled the pressure valve of the gas cylinder to adjust the back pressure at the outlet of the core samples through the back pressure valve during the measurement. The computer connected to the pressure sensor was used to capture the pressure changes at both the inlet and outlet of the core. Different types of glass tubes were used to read the liquid flow, whose volume ranged from 0.1mL to 1.0mL. All of the above designs made the results more reliable.

**Table 1**
Basic parameters of the selected core samples.

| Sample | Length (L/mm) | Diameter (R/mm) | Porosity (φ/%) | Permeability (K/mD) | Mass (M/g) |
|---|---|---|---|---|---|
| 1 | 53.96 | 24.50 | 16.1 | 1.339 | 55.266 |
| 2 | 44.12 | 24.50 | 15.3 | 0.667 | 48.124 |
| 3 | 42.28 | 24.48 | 14.3 | 0.338 | 47.566 |
| 4 | 46.68 | 24.48 | 8.8 | 5.526 | 55.684 |

**Table 2**
The formula of simulated formation water.

| Composition | NaCl | $CaCl_2$ | $MgCl_2$ | $NaHCO_3$ | $Na_2SO4$ | KCl |
|---|---|---|---|---|---|---|
| Dosage (mg/L) | 18673.2 | 33066.9 | 4569.5 | 339.8 | 9046.8 | 409.7 |

### 2.3. Experimental procedures

The liquid flow rate measurement with the apparatus was carried out as follows:

a The cores were evacuated and saturated with simulated formation water for 72h.
b The saturated cores were placed into the core holder, and the simulated formation water was displaced via the pump with a constant flow mode to clear the air abounding in the pipeline.
c The confining pressure was set to 5MPa and the back pressure was set to 0MPa. The displacement mode of the displacement pump was set to a constant pressure, with an initial displacement pressure of 1MPa and the flow rate in the outlet was measured. Counters were read in 30min intervals after 2h. Displacements and consecutive measurements were more than three. The displacement was considered to be constant when the variation in the three measurements was less than 3%. The average of the three continuous measurements was chosen to be the final experimental result.
d The confining pressure and back pressure were kept constant, and the liquid flow rate in the outlet of the core was monitored under different displacement pressure varied in 0.5MPa increments.
e The confining pressure and back pressure were synchronously increased in 1MPa increments to make the effective stress of the core accordant. The initial displacement pressure was set to 1MPa under each back pressure condition, and the flow rate in the outlet was measured. Step *d* was then repeated.

## 3. Results and discussion

### 3.1. Responses of liquid flow rate to back pressure

Core sample $2^{\#}$ was taken as an example to study the effects of back pressure on liquid flow rate, and the results were showed in Fig. 2. Comparison with the results measured under the traditional method with 0MPa back pressure, it can be observed that the liquid flow rate was enhanced at the same displacement pressure with the increasement in back pressure. Furthermore, the rates measured with a back pressure were higher than the rates measured under 0MPa back pressure. When a back pressure of 3MPa was applied at the outlet of the core, the liquid flow rate increased rapidly with the increasement in displacement pressure.

In order to study the variation features of liquid flow rates with the changes of back pressure, liquid flow rates measured under 0MPa back pressure were taken as the datum data to normalize those data measured under a series of back pressures, showed in Fig. 3. According to